D E C L A R A T I O N

I, Takao Ochi, a Japanese Patent Attorney registered No. 10145, of Okabe International Patent Office at No. 602, Fuji Bldg., 2-3, Marunouchi 3-chome, Chiyoda-ku, Tokyo, Japan, hereby declare that I have a thorough knowledge of Japanese and English languages, and that the attached pages contain a correct translation into English of the priority documents of Japanese Patent Application No. 6-204268 filed on August 5, 1994 in the name of CANON KABUSHIKI KAISHA.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made, are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

signed this 13th day of January, 1999

Takao Ochi

TAKAO OCHI

PATENT OFFICE

JAPANESE GOVERNMENT

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[Inventor]	
[Domicile or Residence]	c/o Canon Kabushiki Kaisha 30-2, 3-chome, Shimomaruko, Ohta-ku, Tokyo
[Name]	SHOICHI YAMAZAKI
[Applicant]	
[Identification No.]	000001007
[Name]	CANON KABUSHIKI KAISHA
[Representative]	HAJIME MITARAI
[Attorney]	
[Identification No.]	100086818
[Patent Attorney]	
[Name]	SACHIO TAKANASHI
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[Title of the Invention]

Display Device Having Visual Line Detecting System

[What is claimed is:]

[Claim 1] A display device having a visual line detecting system comprising:

an observation system which guides a light of video information in a visible wavelength region displayed by display means to the eye of the observer without forming an image thereof on the way by using an optical system having a reflecting surface, so as to observe a virtual image of said video information; and

a visual line detecting system which causes a invisible light from light source means to enter the eye of the observer, and guides the light beam reflected from said eye onto a surface of an image pick-up means through a part of said optical system by use of an imaging optical system provided independently of said optical system, so as to detect a visual line of the eye of said observer by use of a signal from said image pick-up means, the video information displayed by said display means being controlled by use of visual line information from said visual line detecting system.

[Claim 2] A display device having a visual line detecting system according to claim 1, wherein said optical system has a prism member for guiding a light beam from video information displayed by said display means to the eye of the observer, and said prism member has a reflecting surface having a function for total reflection with a curvature.

[Claim 3] A display device having a visual line detecting system according to claim 2, wherein said prism member causes a light beam from the video information displayed by said display means to enter through an entrance face, totally reflecting the light beam from said entrance face at a front face having a curvature, and after reflecting the light beam from said front face at a concave face having a curvature, transmitting it through a part of said front face to be guided to the eye of the observer.

[Claim 4] A display device having a visual line detecting system according to claim 3, wherein the front face and/or the concave face of said prism member has a variable refractive power depending on the azimuthal angle.

[Claim 5] A display device having a visual line detecting system according to claim 2, wherein after passing through at least a part of said prism member and a dichroic mirror face, the light beam reflected from the eye of the observer is guided to an imaging optical system of said visual line detecting system.

[Claim 6] A display device having a visual line detecting system according to claim 2, wherein after passing through a dichroic mirror face, the light beam reflected from the eye of the observer is guided to the imaging optical system of said visual line detecting system.

[Claim 7] A display device having a visual line detecting system according to claim 1, characterized by satisfying a condition $0.02 < |\beta| < 0.18$ wherein β is an imaging magnification of said imaging optical system from the eye of said observer to said image pick-up element.

[Claim 8] A display device having a visual line detecting system according to claim 3, characterized by satisfying a condition $|\alpha| \leq 20°$ wherein α is the angle between the tangential line to the front face of said

prism member at the vertex thereof in the cross section in the meridian direction and a line perpendicular to the optical axis of the eye and passing the vertex of said front face.

[Claim 9] A display device having a visual line detecting system comprising:

an observation system which guides a light of video information in a visible wavelength region displayed by display means to the eye of the observer without forming an image thereof on the way by using an optical system having a reflecting face, so as to observe a virtual image of said video information;

a visual line detecting system which causes a invisible light from light source means to enter the eye of the observer, and guides the light beam reflected from said eye onto a surface of an image pick-up means through a part of said optical system by use of an imaging optical system provided independently of said optical system, so as to detect a visual line of the eye of said observer by use of a signal from said image pick-up means; and

video information supply means for supplying the video information to said display means, said video information supply means being adapted to control the

video information displayed by said display means on the basis of visual line information from said visual line detecting system.

[Claim 10] A display device having a visual line detecting system comprising:

an observation system which guides a light of video information in a visible wavelength region displayed by display means to the eye of the observer by using an optical system having a reflecting face with a curvature for effecting total reflection, so as to observe an image of said video information; and

a visual line detecting system which causes a invisible light from light source means to enter the eye of the observer, and guides the light beam reflected from said eye onto a surface of an image pick-up means through a part of said optical system, so as to detect a visual line of the eye of said observer by use of a signal from said image pick-up means, the video information displayed by said display means being controlled by use of visual line information from said visual line detecting system.

[Claim 11] A display device having a visual line detecting system comprising:

an observation system which guides a light of video information in a visible wavelength region displayed by display means to the eye of the observer by using an optical system having a face with a variable refractive power depending on the azimuthal angle, so as to observe an image of said video information; and

a visual line detecting system which causes a invisible light from light source means to enter the eye of the observer, and guides the light beam reflected from said eye onto a surface of an image pick-up means through a part of said optical system, so as to detect a visual line of the eye of said observer by use of a signal from said image pick-up means, the video information displayed by said display means being controlled by use of visual line information from said visual line detecting system.

[Claim 12] A display device having a visual line detecting system according to claim 1 or claim 11, wherein said visual line detecting system has the imaging optical system provided independently of said optical system.

[Claim 13] A display device having a visual line

detecting system according to claim 11, wherein said face with a variable refractive power depending on the azimuthal angle is a reflecting face.

[Claim 14] A display device having a visual line detecting system comprising:

an observation system which guides a light of video information in a visible wavelength region displayed by display means to the eye of the observer by using an optical system having a reflecting face, so as to observe an image of said video information; and

a visual line detecting system which causes a invisible light from light source means to enter the eye of the observer, and guides the light beam reflected from said eye onto a surface of an image pick-up means through a part of said optical system by use of an imaging optical system provided independently of said optical system, so as to detect a visual line of the eye of said observer by use of a signal from said image pick-up means,

wherein the video information displayed by said display means is controlled by use of visual line information from said visual line detecting system, and

a condition $0.02 < |\beta| < 0.18$ is satisfied wherein β is an imaging magnification of said imaging optical

system from the eye of said observer to said image pick-up element.

[Claim 15] A head-up display device, characterized by using a display device having a visual line detecting system according to claim 1, 9, 10, 11 or 14.

[Detailed description of the Invention]

[0001]

[Field of the Industrial Utilization]

The present invention relates to a display device having a visual line detecting system, and particularly to a so-called head-mount display such as a spectacle-type, goggle-type, or helmet-type display device which is mounted on the head of a information visual recognizer (observer) so that video information (displayed information) displayed by display means is guided to the eye of the information visual recognizer to be observed. In such display device, when displayed by the display means to be observed, the video information is controlled in various manners by using a motion of the eye of the observer, that is, a signal from the visual line detecting system for detecting the visual line of the observer.

[0002]

[Prior Art]

Conventionally, various display devices have been proposed which are called head-mount displays mounted on the head of the information visual recognizer (observer) for observing image information which is displayed by the display means by guiding the light of the information to the eye of the observer. Japanese Patent Laid-Open Application No. 3-101709, for example, discloses such display device which is provided with a visual line detecting system for detecting a so-called visual line (visual axis), or the axis in the gazing direction for observation by the observer by utilizing a reflected image of the eye of the observer obtained when the eye of the observer is illuminated, so as to control the image information displayed on the display device by utilizing the visual line information obtained by the visual line detecting system.

[0003]

In the above-mentioned Application, such an optical system is employed which causes an imaging system to form an image of video information displayed by display means such as a CRT on a primary imaging face so that the image information imaged on the primary imaging face can be observed through an

eyepiece system. On the other hand, a light source for emitting infrared rays is provided so as to cause the infrared rays from the light source to enter the eye of the observer by utilizing a part of the optical system. Then, the light beam reflected from the eye are transmitted through a part of the optical system and the infrared rays, and then guided onto the surface of an image pick-up element through a dichroic mirror for reflecting visible light, so as to detect a visual line (motion) of the eye by using an output signal from the image pick-up element.

[0004]

[Problems to be solved by the Invention]

Generally, it is desirable that a display device as a head-mount display should be of a reduced size and weight as a whole because it is mounted on the head of an information recognizer for personal use.

[0005]

The device proposed in the above-mentioned Japanese Patent Laid-Open Application No. 3-101709 employs an optical system of a primary imaging scheme for imaging the image information displayed by the display device once. Accordingly, the visual line detecting system does not require an imaging system exclusive therefor. However, the optical system

becomes complicated as a whole, and the size of the system tends to becomes too large as a device to be mounted on the head of the observer.

[0006]

An object of the present invention is to provide a display device having a visual line detecting system which is capable of controlling a state of observation of the image information displayed by display means of an observation system in various manners based on visual line information while intending of reducing the size of the entire device, by properly constituting the observation system for observing the image information displayed by the display means in a display device such as a head-mount display and the visual line detecting system for detecting the visual line of the observer mounted in a part thereof.

[0007]

[Means for solving the Problems]

A display device having a visual line detecting system of the present invention is characterized as described below.

(1-1) The display device comprises:

an observation system which guides a light of video information in a visible wavelength region displayed by display means to the eye of the observer

without forming an image thereof on the way by using an optical system having a reflecting face, so as to observe a virtual image of the video information; and

a visual line detecting system which causes a invisible light from light source means to enter the eye of the observer, and guides the light beam reflected from the eye onto a surface of an image pick-up means through a part of the optical system by use of an imaging optical system provided independently of the optical system, so as to detect a visual line of the eye of the observer by use of a signal from the image pick-up means, the video information displayed by the display means being controlled by use of visual line information from the visual line detecting system.

[0008]

(1-1-1) The display device is particularly characterized in that the optical system has a prism member for guiding a light beam from video information displayed by the display means to the eye of the observer, and the prism member has a reflecting face for total reflection with a curvature.

[0009]

(1-1-2) The display device is characterized in that the prism member causes a light beam from the video information displayed by the display means to

enter through an entrance face, totally reflecting the light beam from the entrance face at a front face having a curvature, and after reflecting the light beam from the front face at a concave face having a curvature, transmitting it through a part of the front face to be guided to the eye of the observer.

[0010]

(1-1-3) The display device is also characterized in that the front face and/or the concave face of the prism member has a variable refractive power depending on the azimuthal angle.

[0011]

(1-1-4) The display device is also characterized in that, after passing through at least a part of the prism member and a dichroic mirror face, the light beam reflected from the eye of the observer is guided to an imaging optical system of the visual line detecting system.

[0012]

(1-1-5) The display device is also characterized in that, after passing through a dichroic mirror face, the light beam reflected from the eye of the observer is guided to the imaging optical system of the visual line detecting system.

[0013]

(1-2) The display device is characterized by comprising:

an observation system which guides a light of video information in a visible wavelength region displayed by display means to the eye of the observer without forming an image thereof on the way by using an optical system having a reflecting face, so as to observe a virtual image of the video information;

a visual line detecting system which causes a invisible light from light source means to enter the eye of the observer, and guides the light beam reflected from the eye onto a surface of an image pick-up means through a part of the optical system by use of an imaging optical system provided independently of the optical system, so as to detect a visual line of the eye of the observer by use of a signal from the image pick-up means; and

video information supply means for supplying the video information to the display means, the video information supply means being adapted to control the video information displayed by the display means on the basis of visual line information from the visual line detecting system.

[0014]

(1-3) The display device is characterized by

comprising:

an observation system which guides a light of video information in a visible wavelength region displayed by display means to the eye of the observer by using an optical system having a reflecting face with a curvature for effecting total reflection, so as to observe an image of the video information; and

a visual line detecting system which causes a invisible light from light source means to enter the eye of the observer, and guides the light beam reflected from the eye onto a surface of an image pick-up means through a part of the optical system, so as to detect a visual line of the eye of the observer by use of a signal from the image pick-up means, the video information displayed by the display means being controlled by use of visual line information from the visual line detecting system.

[0015]

(1-4) The display device is characterized by comprising:

an observation system which guides a light of video information in a visible wavelength region displayed by display means to the eye of the observer by using an optical system having a face with a variable refractive power depending on the azimuthal

angle, so as to observe an image of the video information; and

a visual line detecting system which causes a invisible light from light source means to enter the eye of the observer, and guides the light beam reflected from the eye onto a surface of an image pick-up means through a part of the optical system, so as to detect a visual line of the eye of the observer by use of a signal from the image pick-up means, the video information displayed by the display means being controlled by use of visual line information from the visual line detecting system.

[0016]

The display device is particularly characterized in that the visual line detecting system has the imaging optical system provided independently of the optical system, and the face with a variable refractive power depending on the azimuthal angle is a reflecting surface.

[0017]

(1-5) The display device is characterized by comprising:

an observation system which guides a light of video information in a visible wavelength region displayed by display means to the eye of the observer

by using an optical system having a reflecting face, so as to observe an image of the video information; and

a visual line detecting system which causes a invisible light from light source means to enter the eye of the observer, and guides the light beam reflected from the eye onto a surface of an image pick-up means through a part of the optical system by use of an imaging optical system provided independently of the optical system, so as to detect a visual line of the eye of the observer by use of a signal from the image pick-up means,

wherein the video information displayed by the display means is controlled by use of visual line information from the visual line detecting system, and

a condition $0.02 < |\beta| < 0.18$ is satisfied wherein β is an imaging magnification of the imaging optical system from the eye of the observer to the image pick-up element.

[0018]

[Embodiments]

Figs. 1 and 2 are partial cross-sectional views showing the optical path of an observation system and a visual line detecting system in an embodiment of the present invention, while Fig. 3 is a partial plan view of the system shown in Fig. 2, and Figs. 4 and 5 are

schematic views showing the mode of use when the device of the present invention is mounted on the head of the observer.

[0019]

In these drawings, there are shown an observer 101, display means 4 composed for example of a liquid crystal display device and serving to display video information in the visible wavelength region, based on signals from video information supply means such as a CD-ROM 105 or a video camera 106, and an optical member 10 consisting of a transparent parallel-faced flat plate and incorporating therein a dichroic mirror 7 serving as a beam splitter for transmitting the visible light and reflecting the infrared light. The dichroic mirror 7 may however be replaced by a simple half mirror.

[0020]

A prism member 3 is provided with a front face 1 consisting of a toric aspherical surface and effecting total reflection in a part; a rear face 6 consisting of a transparent or opaque, flat or curved surface; a concave face 2 consisting of a semi-transmitting or mirror-reflecting toric aspherical surface provided in the prism member 3; and an entrance face 5. An optical axis (central axis) 104 coincides with the optical axis

of the eye 103. The elements in the optical path from the display means 4 to the eye 103 constitute an observation system, for observing a ~~false~~ virtual image of the video information displayed on the display means 4. Light source means 102 projects infrared light (non-visible light wavelength of about 880 nm) to the eye 103, in order to detect the visual line of the eye 103 of the observer 101.

[0021]

When the infrared light from the light source means 102 is projected onto the eye 103 of the observer 101 as shown in Fig. 2, an imaging optical system (imaging lens) 8 forms a corneal reflected image, formed by the light reflected from the cornea of the eye 103, and images of pupil etc. on an image sensor 9 such as a CCD, through the prism member 3 and the dichroic mirror 7 of the optical member 10. The imaging lens 8 is provided independently from the observation system for observing the virtual image of the video information of the display means 4. The elements in the optical path from the light source means 102 to the image sensor 9 by way of the eye 103 constitute a visual line detecting system for detecting the visual line of the eye 103 of the observer 101. In the present embodiment, the elements of the observation

system and the visual line detecting system are designed as explained in the foregoing, thereby facilitating the compactization of the entire system incorporating these two systems.

[0022]

In the following there will be explained, with reference to Fig. 1, the observation system for observing the virtual image of the video information displayed on the display means 4. In the present embodiment, a visible light beam based on the video information displayed on the display means 4 is transmitted by the dichroic mirror face 7 of the optical member 10 and is introduced into the prism member 3 through the entrance face 5 thereof. It is then totally reflected by the front face 1 of the prism member 3, then reflected and condensed by the concave face 2, further transmitted by the front face 1 and guided to the eye 103 of the observer 101. In such configuration, the curvatures of the front face 1 and the concave face 2 are so suitably selected that a virtual image of the video information displayed on the display means 4 is formed in front of the observer 101, without a primary image plane for intermediate image formation.

[0023]

As explained above, in the present embodiment, the observation system is constructed as virtual image type, whereby the observer 101 observes the virtual image of the video information. It is also possible, in the present embodiment, to constitute the concave face 2 with a semi-transmitting surface and the rear face 6 with a transmitting surface, and suitably selecting the curvature of the rear face 6, thereby spatially superimposing the external image information and the virtual image of the video information of the display means 4 for observation in a same viewing field with same visibility.

[0024]

In the observation system of the present embodiment, in displaying the video information on the display means from the video information supply means such as a CD-ROM 105 or a video camera 106 held by the observer 101 as shown in Figs. 4 and 5, the visual line information of the eye of the observer, obtained by the visual line detecting system, is utilized for various controls, such as auto focusing (focusing of the video camera), electronic zooming (electrical enlargement of the information in the direction of the visual line), zooming (calculation of the focal length f of the video camera for obtaining an image frame size extracted by

the visual line and matching to said focal length), and menu selection (light metering, flash panorama size etc.) selected by the visual line.

[0025]

In the following there will be explained, with reference to Fig. 2, the visual line detecting system for detecting the visual line of the eye 103 of the observer 101. The eye 103 of the observer 101 is illuminated with the infrared light from the light source means 102, and the infrared light reflected by the cornea of the eye 103 is transmitted by the front face 1 of the prism member 3, then reflected by the concave face 2, further totally reflected by the front face 1, transmitted by the entrance face 5 and guided into the optical member 10. It is then reflected by the dichroic mirror face 7 thereof, totally reflected by a face 10a thereof and is guided to the image sensor 9 through the imaging lens 8.

[0026]

The imaging lens 8 is employed because the observation system thereof is of a virtual image type and has no imaging function so as to form the corneal reflected image and the images of the pupil etc. of the eye 103 on the image sensor 9, and the visual line of the eye 103 is detected from the signal of said image

sensor 9.

[0027]

In the present embodiment, the visual line of the eye is detected by a method disclosed for example in the Japanese Patent Laid-Open Application Nos. 1-274736 and 3-11492 of the present applicant.

[0028]

(A) and (B) in Fig. 6 are schematic cross-sectional views of the prism member 3 employed in the present embodiment. It is employed in this case as an observation system, but, in case it is employed as the visual line detecting system, the optical functions remain some except that the optical path is reversed. A light beam 4a, perpendicularly emitted from the display face of the display means 4 is transmitted by the entrance face 5 of the prism member 3 and enters the toric aspherical front face 1 with an incident angle at least equal to 43°, thereby being totally reflected by said front face 1. The light beam 4a is then introduced into the toric aspherical concave face 2 with an incident angle not exceeding 43°, thereby being reflected by the concave face and is emitted from the front face 1.

[0029]

The front face 1 is curved, and effects total

reflection in a part and transmission in another part. It is therefore equivalent to two curved surfaces, and, in combination with the concave face 2, there is constituted a reflective optical system having three curved surfaces. In this manner the focal length of the entire optical system is shortened (20 to 25 mm in the following numerical examples), whereby the entire optical system can be compactized.

[0030]

In the present embodiment, a toric surface, a toric aspherical surface or an anamorphic aspherical surface with variable refractive power, i.e., variable curvature, depending on the azimuthal angle is employed in the front face 1, the concave face 2 and the entrance face 5 in the observation system and the visual line detecting system 5, whereby satisfactory correction is attained for the eccentric aberration generated when the angle between the incident light and the emerging light of the concave mirror 2 is made large in order to reduce the size of the entire optical system.

[0031]

The curvatures of the front face 1 and the rear face 6 are so selected as to constitute a meniscus lens having a small refractive power for the light passing

through these faces, whereby the external image information such as the external scenery can be satisfactorily observed through the rear face 6.

[0032]

Also in the cross section in the meridian direction, the front face 1 is given a negative refractive power, in order to correct the aberrations generated by the positive refractive power of the concave face 2. The meridian direction means a plane perpendicular to the plane containing the optical path from the center of the image on the display means to the designed center of the eye (i.e. direction perpendicular to the plane of the drawing sheet of Fig. 6).

[0033]

Also in the present embodiment, the front face 1 may be given a negative refractive power in the cross section in the generatrix direction, for attaining an effect similar to that of the negative refractive power in the cross section in the meridian direction. The cross section in the generatrix direction means a plane containing the optical path from the center of the image of the display means to the designed center of the eye (i.e. plane of the drawing sheet of Fig. 6).

[0034]

There is satisfied a condition:

$|\alpha| \leq 20°$ ... (1)

wherein α is the tilt angle, as shown in (B) of Fig. 6, between a tangential line L at the vertex of the front face 1 in the cross section in the generatrix direction and a line m perpendicular to the optical axis 104 of the eye and passing the vertex of the front face 1. As indicated by the condition (1), the angle α is selected smaller than 20°, thereby reducing the distortion in observation of the virtual image of the video information of the display means 4 and the external image information such as external scenery in spatially superimposed state, and reducing the thickness of the prism in the axial direction.

[0035]

In the following there will be explained other features of the observation system and the visual line detecting system including the elements (entrance face 5, front face 1 and concave face 2) provided in the optical path from the display means 4 to the eye 103.

[0036]

(2-1) In the present embodiment, the imaging magnification β of the imaging lens 8 from the eye 103 to the image sensor 9 is defined by:

$0.02 < |\beta| < 0.18$ ... (2)

Above the upper limit of the condition (2), the magnification of the eye image becomes too large, so that the effective diameter of the image sensor becomes undesirably large. Also below the lower limit of the condition (2), the focal length of the visual line detecting system has to be made shorter, whereby various aberrations are generated and a satisfactory eye image cannot be obtained.

[0037]

(2-2) Also there is satisfied a condition:

$$0.9 < |f_y/f_x| < 1.1 \qquad \ldots (3)$$

wherein f_y, f_x are focal lengths of the entire system respectively in the generatrix cross section and the meridian cross section, thereby maintaining a substantially constant focal length for the entire system in any azimuthal angle and dispensing with the correction for the aspect ratio, in the generatrix direction and the meridian direction, of the video information displayed on the display means.

[0038]

(2-3) Also there is satisfied a condition:

$$|R_x| < |R_y| \qquad \ldots (4)$$

wherein R_y, R_x are radii of paraxial curvature of the concave face 2 respectively in the generatrix cross section and the meridian cross section. For

compactizing the observation system, the optical axis of the concave face has to be significantly tilted clockwise, in the generatrix cross section, from the optical axis of the eye, but such configuration generates a large eccentric aberration. On the other hand, in the meridian cross section, such eccentric aberration is not generated much because there is little room for such eccentricity. In the present embodiment, therefore, the radius R_y of curvature in the generatrix cross section is selected larger than that R_x in the meridian cross section as indicated by the condition (4), or the refractive power in the generatrix direction is selected weaker than that in the meridian direction, thereby suppressing the eccentric aberration in the generatrix cross section.

[0039]

In the present embodiment, for the purpose of correction of the eccentric aberration, the condition (4) is preferably set as follows:

$$|R_x/R_y| < 0.85 \quad \ldots (5)$$

[0040]

(2-4) When the entrance face 5 of the prism member 3 is constituted by a toric surface or an anamorphic surface, there is selected a condition:

$$|R_{y5}| < |R_{x5}| \quad \ldots (6)$$

wherein R_{y5} and R_{x5} are radii of curvature respectively in the generatrix cross section and the meridian cross section. The entrance face 5 generates relatively little eccentric aberration in the generatrix cross section. Thus, though the concave face 2 and the front face 1 cannot be given strong refractive forces in the generatrix cross section, the entrance face 5 is given a strong refractive force in the generatrix cross section, thereby realizing a substantially constant focal length in any azimuthal angle in the entire system.

[0041]

(2-5) Satisfactory optical performance is realized in the meridian cross section by giving a negative refractive power to the totally reflecting area of the front face 1, a positive refractive power to the concave face 2 and a negative refractive power to the transmitting area of the front face 1. In case the entrance face 5 has a refractive power, it is preferably selected as positive in the generatrix cross section, in order to cover the deficiency in the positive refractive power in the generatrix cross section in the entire system.

[0042]

(2-6) Satisfactory optical performance is

realized in the generatrix cross section by giving a negative refractive power in the totally reflecting area of the front face 1, and a positive refractive power to the concave face 2. In case the entrance face 5 has a refractive power, it is selected as positive in the meridian cross section, thereby reducing the aberrations in the meridian cross section.

[0043]

(2-7) In the meridian cross section, there are satisfied condition:

$$0.1 < |2f_x/R_{x1}| < 2.0 \quad \cdots (7)$$

$$0.5 < |2f_x/R_{x2}| < 2.5 \quad \cdots (8)$$

wherein R_{x1}, R_{x2} are radii of curvature respectively of the totally reflecting area of the front face 1 and of the concave face 2, and f_x is the focal length of the entire system. The upper limits of the conditions (7), (8) correspond to stronger refractive forces of said curvatures, while the lower limits correspond to the weaker refractive forces. Above the upper limit of the condition (7), the distortion aberration becomes difficult to correct, and, below the lower limit, the totally reflecting condition becomes difficult to satisfy. Also above the upper limit of the condition (8), the astigmatism becomes difficult to correct, and, below the lower limit, the entire optical system

becomes larger, particularly with a larger thickness in the direction parallel to the optical axis.

[0044]

(2-8) In the generatrix cross section, there are satisfied condition:

$$0 < |2f_y/R_{y1}| < 1.0 \quad \ldots (9)$$

$$0.2 < |2f_y/R_{y2}| < 2.5 \quad \ldots (10)$$

wherein R_{y1}, R_{y2} are radii curvature respectively of the totally reflecting area of the front face 1 and the concave face 2, and f_y is the focal length of the entire system. The upper limits of the conditions (9) and (10) correspond to stronger refractive powers of said curvatures, while the lower limits correspond to weaker refractive powers. Above the upper limit of the condition (9), the eccentric distortion aberration becomes difficult to correct, while, below the lower limit, it becomes difficult to satisfy the totally reflecting condition. Also above the upper limit of the condition (10), eccentric astigmatism is generated significantly, and, below the lower limit, the length of the entire lens increases and the entire optical system becomes undesirably bulky.

[0045]

(2-9) The concave face 2 is shifted in parallel manner, in the generatrix cross section (Y-direction),

from the optical axis 104 of the eye toward the display means 4, thereby suppressing the eccentric distortion aberration in the generatrix cross section. The amount E of parallel shift (distance from the optical axis 104 to the vertex of the concave face 2 as shown in (B) of Fig. 6) is so selected as to satisfy:

$25 \le E$ ... (11)

thereby satisfactorily correcting the eccentric distortion.

[0046]

(2-10) The tilt angle α in the condition (1) is so maintained as to satisfy:

$-1.5° \le \alpha \le 5°$ ... (12)

for effectively compactizing the entire optical system. Below the lower limit of the condition (12), the image information becomes distorted significantly, while, above the upper limit, the prism member 3 becomes thicker in the direction of the optical axis 104.

[0047]

Figs. 7 to 10 are schematic views showing modifications in a part of the visual line detecting system in the vicinity of the prism member 3 of the embodiments 2 to 5 of the present invention.

[0048]

An embodiment 2 shown in Fig. 7 is different from

the embodiment 1 in that the optical member 10 is provided between the eye 103 of the observer and the prism member 3, with corresponding positioning of the imaging lens 8 and the image sensor 9. This embodiment provides an advantage of exact detection of the visual line, since no eccentric face is involved in the visual line detecting system.

[0049]

An embodiment 3 shown in Fig. 8 is different from the embodiment 1 in that the dichroic face 7 is provided in inclined manner inside the prism member 3, with corresponding positioning of the imaging lens 8 and the image sensor 9. The other arrangements are the same in the both embodiments. This embodiment is featured by a reduced number of components, leading to further compactization of the entire optical system.

[0050]

In an embodiment 4 shown in Fig. 9, the optical member 10 is positioned farther than the prism member 3 from the eye 103, compared with that in the embodiment 1. Also the concave face 2 is provided with a dichroic film reflecting the visible light and transmitting the infrared light. The optical member 10 is provided with an inclined reflecting face 11, having a semi-transmitting, totally reflecting or dichroic film, and

the imaging lens 8 and the image sensor 9 are positioned accordingly. The other arrangements are the same in the both embodiments. The state of mounting of the device of the present embodiment, on the head of the observer, is schematically illustrated in Fig. 11.

[0051]

An embodiment 5 shown in Fig. 10 is different from the embodiment 1 in that the optical member 10 consisting of a parallel-faced flat plate is replaced by a dichroic mirror 7, transmitting the visible light and reflecting the infrared light, provided on the entrance face 5 of the prism member 3, and the imaging lens 8 and the image sensor 9 are positioned accordingly. The other arrangements are the same in the both embodiments. The state of mounting of the device of the present embodiment, on the head of the observer, is schematically illustrated in Fig. 12.

[0052]

Display devices utilizing the visual line detecting systems of the above-explained embodiments can be directly applied to so-called head-up display device.

[0053]

In the following there are shown numerical examples of the present embodiment, wherein elements of

the system are represented as follows, with reference to Figs. 1 to 3:

(1) eye 103 being selected as the original point (0, 0) of the coordinate system;

(2) in the visual line detecting system, in tracing the light from the eye 103;

i = 1 eye

i = 2 front face 1 (transmitting face)

i = 3 concave face 2

i = 4 front face (totally reflecting face)

i = 5 entrance face 5

i = 6 entrance face of optical member 10

i = 7 dichroic face

i = 8

i = 9 exit face of optical member 10

i = 10 entrance face of imaging lens

i = 11 exit face of imaging lens

i = 12 image sensor

in the observation system;

i = 8 entrance face of video information

i = 9 display face of video information

(3) TAL indicates a toric aspherical surface; and AAL indicates an anamorphic aspherical surface.

[0054]

The TAL is defined, in the generatrix (Y - Z)

cross section, by the following aspherical equation:

[0055]

[Numerical Formula 1]

$$z=\frac{y^2/r_{yi}}{1+\sqrt{1-(1+k_i)(y/r_{yi})^2}}+A_i y^4+B_i y^6+C_i y^8+D_i y^{10}$$

wherein i indicates the face number, and is spherical in the meridian (X - Z) cross section.

[0056]

Also the AAL is defined by:

[0057]

[Numerical Formula 2]

$$z=\frac{y^2/r_{iy}+x^2/r_{ix}}{1+\sqrt{1-\{(1+k_{yi})(y/r_{yi})^2+(1+k_{xi})(x/r_{xi})^2\}}}$$

$$+AR_i\{(1+AP_i)y^2+(1-AP_i)x^2\}^2+BR_i\{(1+BP_i)y^2+(1-BP_i)x^2\}^3$$
$$+CR_i\{(1+CP_i)y^2+(1-CP_i)x^2\}^4+DR_i\{(1+DP_i)y^2+(1-DP_i)x^2\}^5$$

wherein i indicates the face number.

[0058]

Also in the present invention, AL indicates a (rotationally symmetrical) aspherical surface, which is defined by:

[0059]

[Numerical Formula 3]

$$z=\frac{y^2/r_{Yi}}{1+\sqrt{1-(1+k_i)\ (y/r_{Yi})^2}}+A_iy^4+B_iy^6+C_iy^8+D_iy^{10}$$

wherein i indicates the face number. The surface vertex coordinate (Y, Z) is an absolute coordinate when the vertex of the eye surface is taken as (0, 0). The tilt angle in the generatrix cross section indicates the tilt angle of the optical axis of each face, with respect to the optical axis of the eye, said angle being taken positive anticlockwise. A reflecting face (including totally reflecting face) is indicated by a suffix M. nd and νd respectively indicate the refractive index and the Abbe's number for d-line.

[Nemerical Example 1]

(Visual line detecting system)

[0060]

[Composed Font 1]

	r_{yi} Radius of curvature in generatrix cross section	r_{xi} Radius of curvature in meridian cross section	Vertex coordinate Y, Z	Tilt angle in generatrix cross section		
i= 1	∞		(0, 0)	0 °	eye	
i= 2	-514.575	-52.805	(0, 21.15)	0	TAL	nd=1.49171 ν d=57.4
i= 3	-63.546	-42.575	(26.30, 35.96)	-3.33	TAL-M	
i= 4	-514.575	-52.805	(0, 21.15)	0	TAL-M	
i= 5	∞		(20.72, 28.06)	65.37		
i= 6	∞		(21.18, 28.27)	65.37		nd=1.51633 ν d=64.1
i= 7	∞		(23.41, 28.20)	30.37	M	
i= 8	∞		(21.18, 28.27)	65.37	M	
i= 9	∞		(24.93, 20.09)	-54.64		
i=10	-1.889		(26.90, 21.14)	-54.64	AL	nd=1.49171 ν d=57.4
i=11	1.426		(29.35, 19.41)	-54.64	AL	
i=12	∞		(30.51, 18.95)	-51.60	image sensor	

(Observation system)

i= 8	∞	(23.91, 29.52)	65.37		nd=1.51633 ν d=64.1
i= 9	∞	(24.98, 30.01)	59.37	image information	

(TAL, AL data)

TAL2, 4:K=460.670,	A=-0.227E-5,	B=0.179E-7,	C=-0.453E-10,	D=0.429E-13
TAL3 : K=1.105,	A=-0.709E-6,	B=-0.273E-8,	C=-0.191E-11,	D=0.631E-15
AL10 : K=-3.858,	A=0.851E-2,	B=-0.101,	C=0.149,	D=-0.755E-1
AL11 : K=-0.113,	A=0.195,	B=-0.590,	C=0.471,	D=-0.138

(1) $\alpha=0$	(5) $\lvert Rx1/Ry1\rvert=0.10$	(8) $2fx/Rx2=-1.09$	(11) $E=26.3$
(2) $\lvert\beta\rvert=0.10$	$\lvert Rx2/Ry2\rvert=0.67$	(9) $2fy/Ry1=-0.04$	
(3) $\lvert fy/fx\rvert=1.00$	(7) $2fx/Rx1=-0.88$	(10) $2fy/Ry2=-0.36$	

[Nemerical Example 2]

(Visual line detecting system)

[0061]

[Composed Font 2]

	r_{Yi} Radius of curvature in generatrix cross section	r_{xi} Radius of curvature in meridian cross section	Vertex coordinate Y, Z	Tilt angle in generatrix cross section		
i= 1	∞		(0, 0)	0°	eye	
i= 2	-514.575	-52.805	(0, 21.15)	0	TAL	nd=1.49171 ν d=57.4
i= 3	-63.546	-42.575	(26.30, 35.96)	-3.33	TAL	
i= 4	-514.575	-52.805	(0, 34.15)	0	TAL	
i= 5	∞		(0, 37.15)	45	M	
i= 6	-1.889		(-13.0, 37.15)	90	AL	nd=1.49171 ν d=57.4
i= 7	1.426		(-16.0, 37.15)	90	AL	
i= 8	∞		(-17.27, 37.15)	90	image sensor	

(Observation system)

i= 3	-63.546	-42.575	(26.30, 35.96)	-3.33	TAL-M	nd=1.51633 ν d=64.1
i= 4	-514.575	-52.805	(0, 21.15)	0	TAL-M	
i= 5	∞		(20.72, 28.06)	65.37		
i= 6	∞		(24.05, 29.59)	54.25	image information	

(TAL, AL data)

TAL2, 4:	K=460.670,	A=-0.227E-5,	B=0.179E-7,	C=-0.453E-10,	D=0.429E-13
TAL3 :	K=1.105,	A=-0.709E-6,	B=0.273E-8,	C=-0.191E-11,	D=0.631E-15
AL6 :	K=-3.858,	A=0.851E-2,	B=-0.101,	C=0.149,	D=-0.755E-1
AL7 :	K=-0.113,	A=0.195,	B=-0.590,	C=0.471,	D=-0.138

(1) α =0 (5) |Rx1/Ry1|=0.10 (8) 2fx/Rx2=-1.09 (11) E=26.3

(2) | β | =0.05 |Rx2/Ry2|=0.67 (9) 2fy/Ry1=-0.04

(3) | fy/fx | =1.00 (7) 2fx/Rx1=-0.88 (10) 2fy/Ry2=-0.36

[Nemerical Example 3]

(Visual line detecting system)

[0062]

[Composed Font 3]

	r_{yi} Radius of curvature in generatrix cross section	r_{xi} Radius of curvature in meridian cross section	Vertex coordinate Y, Z	Tilt angle in generatrix cross section		
i= 1	∞		(0, 0)	0°	eye	
i= 2	-2158.074	-32.224	(0.60, 19.85)	-10.55	AAL	nd=1.49171 νd=57.4
i= 3	-63.157	-32.870	(34.76, 30.92)	15.81	AAL-M	
i= 4	-2158.074	-32.224	(0.60, 19.85)	-10.55	AAL-M	
i= 5	72.108	1049.744	(14.82, 29.02)	53.74	AAL	
i= 6	∞		(14.98, 29.14)	53.74		nd=1.51633 νd=64.1
i= 7	∞		(17.19, 29.51)	18.74	M	
i= 8	∞		(14.98, 29.14)	53.74	M	
i= 9	∞		(20.31, 21.88)	-66.27		
i=10	-1.889		(22.03, 23.31)	-66.27	AL	nd=1.49171 νd=57.4
i=11	1.426		(24.77, 22.10)	-66.27	AL	
i=12	∞		(25.96, 21.91)	-63.23	image sensor	
(Observation system)						
i= 8	∞		(17.40, 30.91)	53.74		nd=1.51633 νd=64.1
i= 9	∞		(18.21, 31.50)	44.74	image information	

(AAL, AL data)

AAL2, 4:

Ky=-13763. 5, AR=-0. 170E-4, BR=0. 406E-7, CR=-0. 154E-9, DR=0. 223E-12

Kx=-3. 896, AP=-0. 245, BP=0. 416E-1, CP=0. 870E-1, DP=-0. 203E-1

AAL3:

Ky=1. 238, AR=-0. 317E-5, BR=0. 248E-8, CR=-0. 179E-11, DR=0. 608E-15

Kx=0. 279, AP=-0. 249, BP=0. 327E-2, CP=-0. 192E-1, DP=0. 181E-1

AAL5:

Ky=6. 825, AR=-0. 114E-4, BR=-0. 402E-6, CR=0. 113E-8, DR=-0. 411E-10

Kx=-1. 33E+6, AP=0. 273E+1, BP=0. 155E+1, CP=0. 160E+1, DP=-0. 644

AL10 : K=-3. 858, A=0. 851E-2, B=-0. 101, C=0. 149, D=-0. 755E-1

AL11 : K=-0. 113, A=0. 195, B=-0. 590, C=0. 471, D=-0. 138

(1) α =-10. 5 (5) |Rx1/Ry1|=0. 01 (8) 2fx/Rx2=-1. 47 (11) E=34. 8

(2) | β | =0. 12 |Rx2/Ry2|=0. 52 (9) 2fy/Ry1=-0. 02

(3) | fy/fx | =0. 96 (7) 2fx/Rx1=-1. 5 (10) 2fy/Ry2=-0. 73

[Nemerical Example 4]

(Visual line detecting system)

[0063]

[Composed Font 4]

	r_{yi} Radius of curvature in generatrix cross section	r_{xi} Radius of curvature in meridian cross section	Vertex coordinate Y, Z	Tilt angle in generatrix cross section		
i= 1	∞		(0, 0)	0 °	eye	
i= 2	-9423.260	-47.769	(0, 20.38)	1.50	AAL	nd=1.49171 ν d=57.4
i= 3	-65.701	-36.469	(33.13, 29.99)	14.29	AAL-M	
i= 4	-9433.260	-47.769	(0, 20.38)	1.50	AAL-M	
i= 5	7188.930	-49.971	(16.33, 26.54)	62.55	AAL	
i= 6	∞		(19.89, 27.27)	21.55	M	
i= 7	-1.889		(21.28, 20.34)	-11.45	AL	nd=1.49171 ν d=57.4
i= 8	1.426		(21.88, 17.39)	-11.45	AL	
i= 9	∞			-8.45	image sensor	
(Observation system)						
i= 7	∞		(21.11, 29.03)	55.43	image information	

(AAL, AL data)

AAL2, 4:

Ky=-361850, AR=-0.183E-4, BR=0.381E-7, CR=-0.114E-9, DR=0.153E-12

Kx=-13.802, AP=-0.317, BP=-0.602E-1, CP=0.272E-1, DP=-0.211E-1

AAL3:

Ky=1.227, AR=-0.209E-5, BR=0.308E-8, CR=-0.190E-11, DR=0.505E-15

Kx=0.172, AP=0.472, BP=0.553E-1, CP=-0.265E-1, DP=0.751E-2

AAL5:

Ky=987000, AR=-0.871E-5, BR=-0.264E-6, CR=0.469E-13, DR=0.137E-11

Kx=-70.169, AP=41.763, BP=-0.395, CP=0.183E+2, DP=-0.988

AL7 : K=-3.858, A=0.851E-2, B=-0.101, C=0.149, D=-0.755E-1

AL8 : K=-0.113, A=0.195, B=-0.590, C=0.471, D=-0.138

(1) α=1.5 (5)|Rx1/Ry1|=0.005 (8) 2fx/Rx2=-1.22 (11) E=33.1

(2) | β | =0.10 |Rx2/Ry2|=0.56 (9) 2fy/Ry1=-0.46

(3) | fy/fx | =1.00 (7) 2fx/Rx1=-0.93 (10) 2fy/Ry2=-0.61

[Nemerical Example 5]

(Visual line detecting system)

[0064]

[Composed Font 5]

	r_{yi} Radius of curvature in generatrix cross section	r_{xi} Radius of curvature in meridian cross section	Vertex coordinate Y, Z	Tilt angle in generatrix cross section		
i= 1	∞		(0, 0)	0°	eye	
i= 2	-9538.246	-47.590	(0, 21.30)	7.28	AAL	nd=1.49171 νd=57.4
i= 3	-65.6	-36.035	(32.96, 31.40)	14.67	AAL-M	
i= 4	-9538.246	-47.590	(0, 21.30)	0.28	AAL-M	
i= 5	225.188	727.642	(16.47, 28.45)	65.28	AAL	
i= 6	∞		(16.92, 28.60)	67.28		nd=1.51633 νd=64.1
i= 7	∞		(19.15, 28.51)	35.28	M	
i= 8	∞		(16.92, 28.66)	67.28	M	
i= 9	∞		(19.69, 29.82)	67.28	M	
i=10	∞		(23.55, 20.60)	-167.72		
i=11	1.889		(21.38, 20.05)	-167.72	AL	nd=1.49171 νd=57.4
i=12	-1.426		(20.74, 17.12)	-167.72	AL	
i=13	∞		(20.19, 16.01)	-164.69	image sensor	nd=1.51633 νd=64.1

(Observation system)

i= 8	∞	(19.69, 29.82)	67.28		
i= 9	∞	(22.02, 29.17)	54.10	image information	

(AAL, AL data)

AAL2, 4:

Ky=-387540, AR=-0. 183E-4, BR=0. 378E-7, CR=-0. 117E-9, DR=0. 158E-12

Kx=-20. 897, AP=-0. 300, BP=-0. 548E-1, CP=0. 326E-1, DP=-0. 228E-1

AAL3:

Ky=1. 213, AR=-0. 224E-5, BR=0. 305E-8, CR=-0. 190E-11, DR=0. 500E-15

Kx=0. 165, AP=-0. 464, BP=0. 630E-1, CP=-0. 251E-1, DP=0. 380E-2

AAL5:

Ky=559. 028, AR=-0. 675E-5, BR=0. 182E-6, CR=0. 212E-12, DR=-0. 189E-10

Kx=-99429. 4, AP=0. 486E+1, BP=-0. 125E+1, CP=0. 111E+2, DP=-0. 789

AL11 : K=-3. 858, A=0. 851E-2, B=-0. 101, C=0. 149, D=-0. 755E-1

AL12 : K=-0. 113, A=0. 195, B=-0. 590, C=0. 471, D=-0. 138

(1) α =0. 28 (5) |Rx1/Ry1|=0. 005 (8) 2fx/Rx2=-1. 26 (11) E=33. 0

(2) | β | =0. 11 |Rx2/Ry2|=0. 55 (9) 2fy/Ry1=-0. 005

(3) | fy/fx | =1. 00 (7) 2fx/Rx1=-0. 95 (10) 2fy/Ry2=-0. 69

[0065]

[Effect of the Invention]

According to the present invention, as explained in the foregoing, there is provided a display device, such as a head-mount display, enabling compactization and provided with a visual line detecting system capable of controlling, based on the visual line information, the observation state of the video information displayed by the display means in the observation system, by suitably designing said observation system for observing the video information displayed by the display means and the visual line detecting system provided, in a part of the observation system, for detecting the visual line of the observer.

[Brief Description of the Drawings]

[Fig. 1]

A schematic view showing the optical path of an observation optical system of the embodiment of the present invention.

[Fig. 2]

A schematic view showing the optical path of a visual line detecting system of the embodiment 1 of the present invention.

[Fig. 3]

A schematic view showing the optical path of the

visual line detecting system of the embodiment 1 of the present invention.

[Fig. 4]

A schematic view showing a state when the display device of the present invention is worn by the observer.

[Fig. 5]

A schematic view showing a state when the display device of the present invention is worn by the observer.

[Fig. 6]

Partial magnified views of Fig. 1.

[Fig. 7]

A partial schematic view in the vicinity of a prism member in the embodiment 2 of the present invention.

[Fig. 8]

A partial schematic view in the vicinity of a prism member in the embodiment 3 of the present invention.

[Fig. 9]

A partial schematic view in the vicinity of a prism member in the embodiment 4 of the present invention.

[Fig. 10]

A partial schematic view in the vicinity of a prism member in the embodiment 5 of the present invention.

[Fig. 11]

Schematic views showing the optical paths of an observation system and a visual line detecting system in the embodiment 4 of the present invention.

[Fig. 12]

Schematic views showing the optical paths of an observation system and a visual line detecting system in the embodiment 5 of the present invention.

[Description of Reference Numerals or Symbols]

1 ... Front face

2 ... Concave face

3 ... Prism member

4 ... Display means

5 ... Entrance face

6 ... Rear face

7 ... Dichroic mirror face

8 ... Imaging optical system

9 ... Image sensor

10 ... Optical member

101 ... Observer

102 ... Light source means

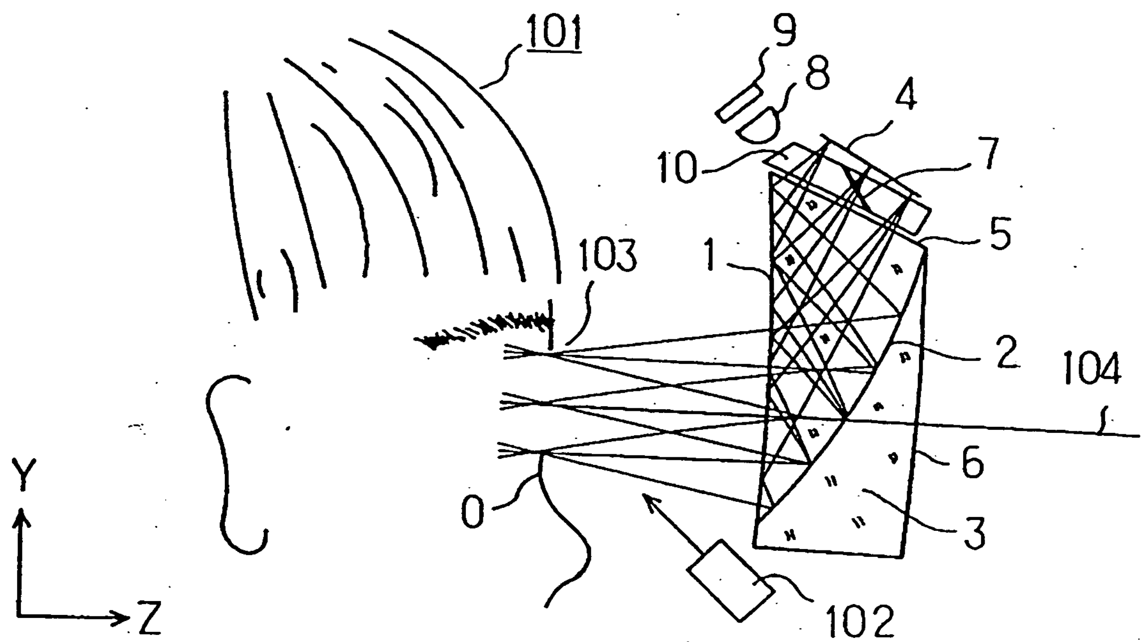
103 ... Eye

104 ... Optical axis

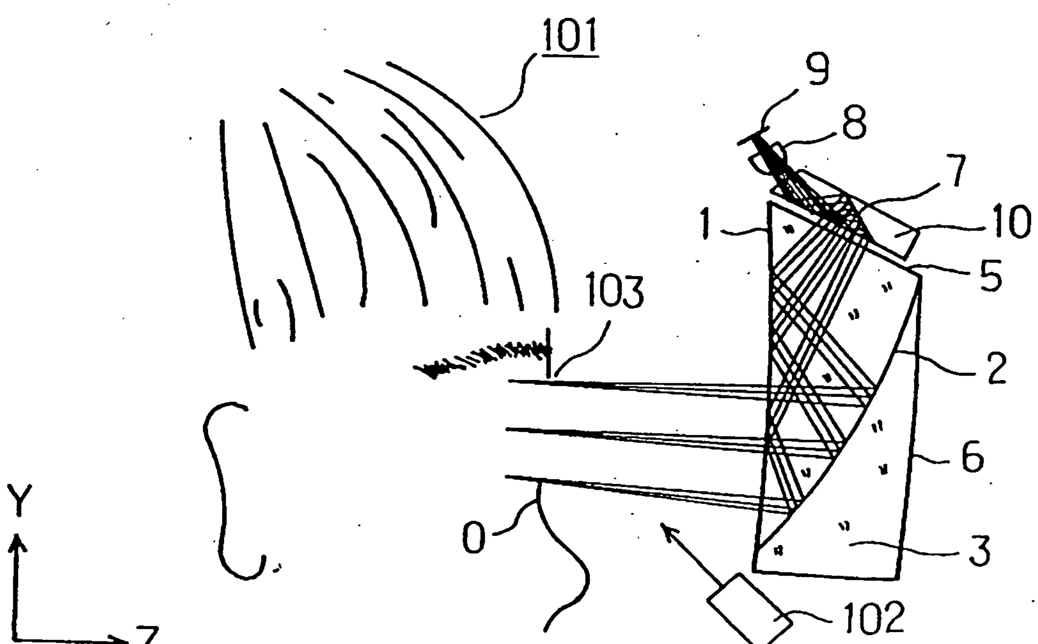
105 ... Video information supply means

【書類名】　図面 [Name of the Document] Drawings

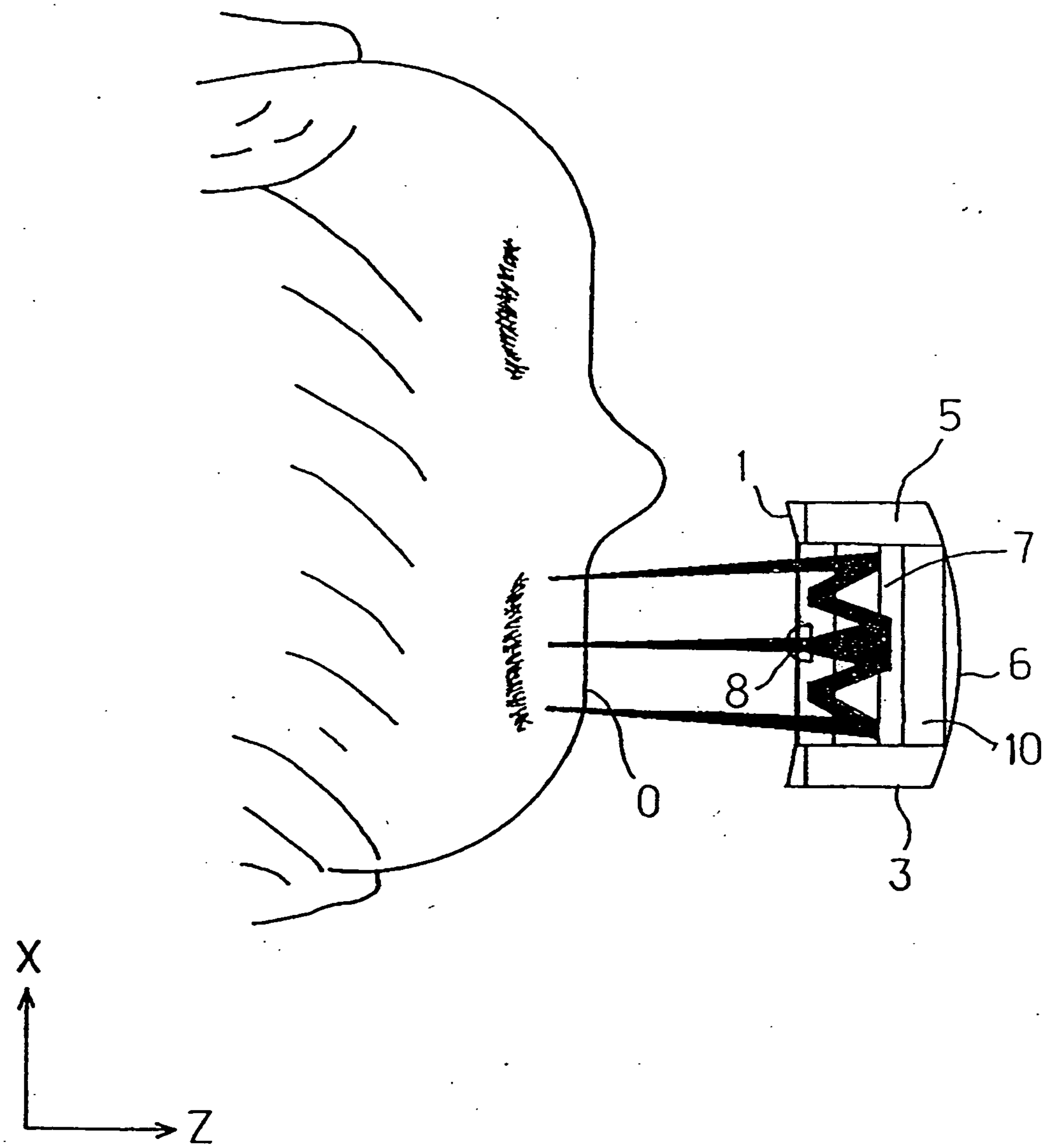
【図１】 Fig 1



【図２】 Fig 2



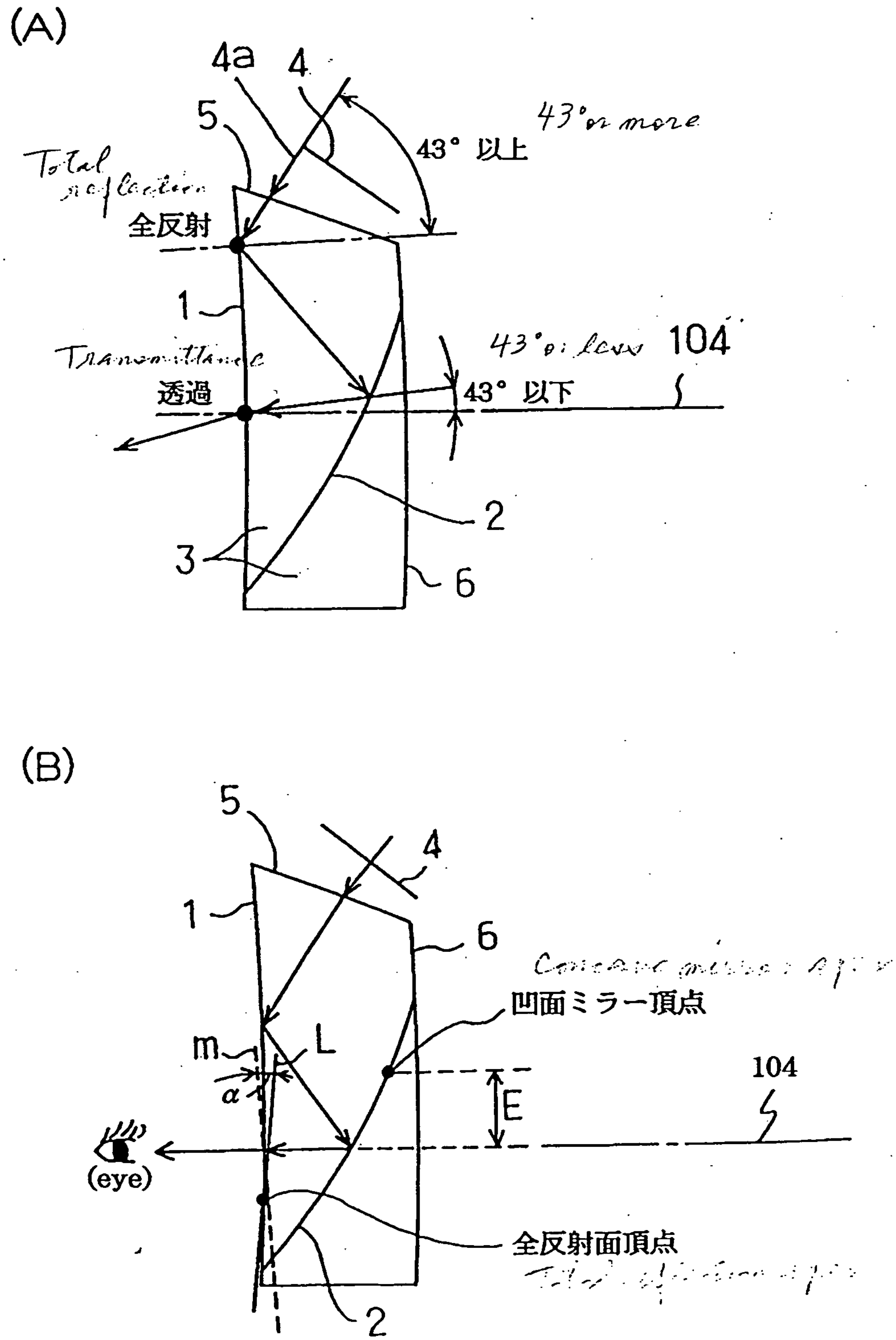
【図３】 Fig. 3



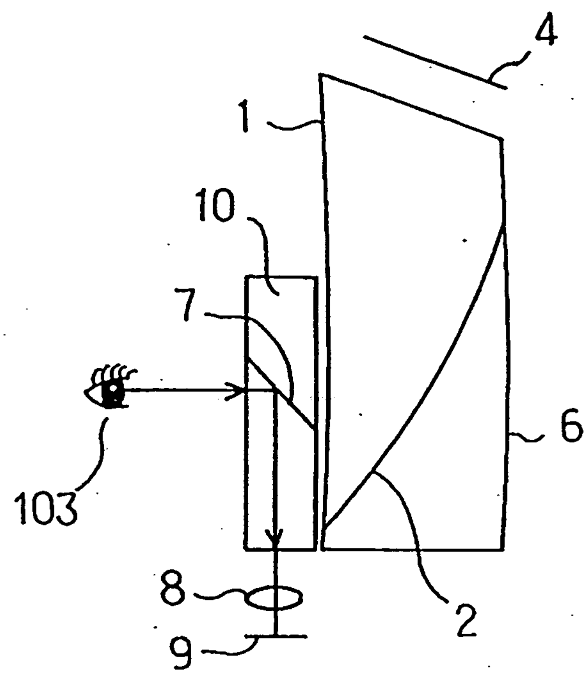
【図４】 Fig.4

【図５】 Fig.5

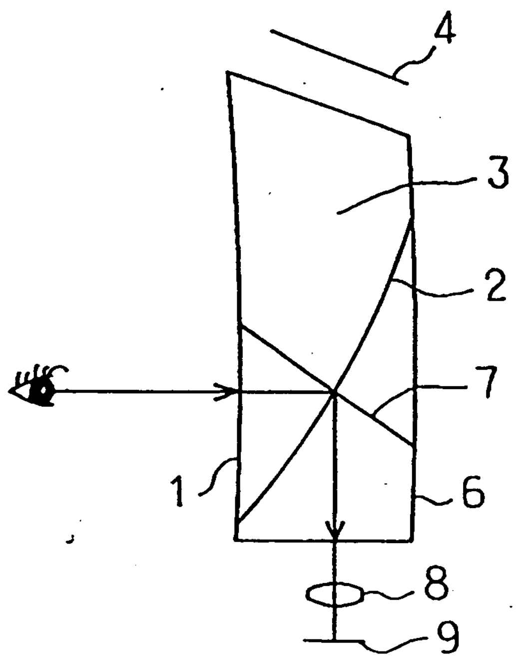
【図６】 Fig. 6


(A)
4a
4
5
43° 以上
43° or more
Total reflection
全反射
1
43° or less
104
Transmittance
透過
43° 以下
2
3
6
(B)
5
4
1
6
Concave mirror apex
凹面ミラー頂点
m
L
α
104
E
(eye)
全反射面頂点
2

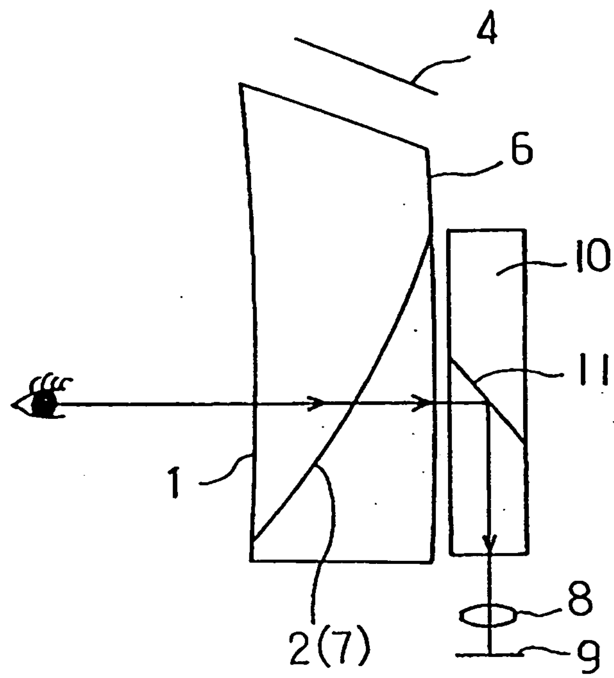
【図７】 Fig. 7



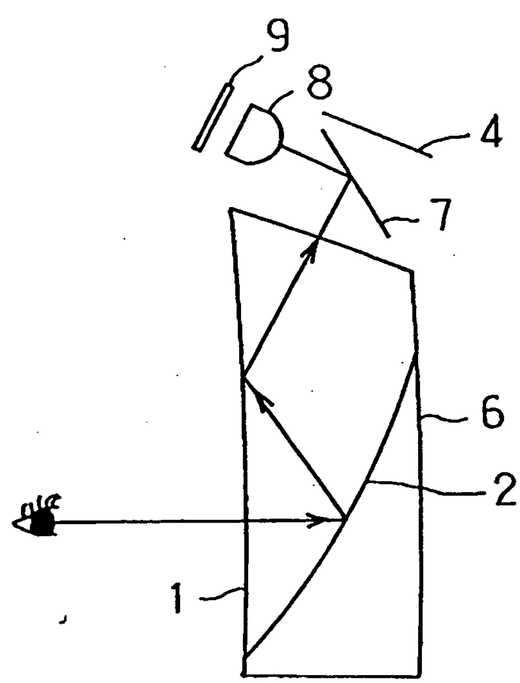
【図８】 Fig. 8



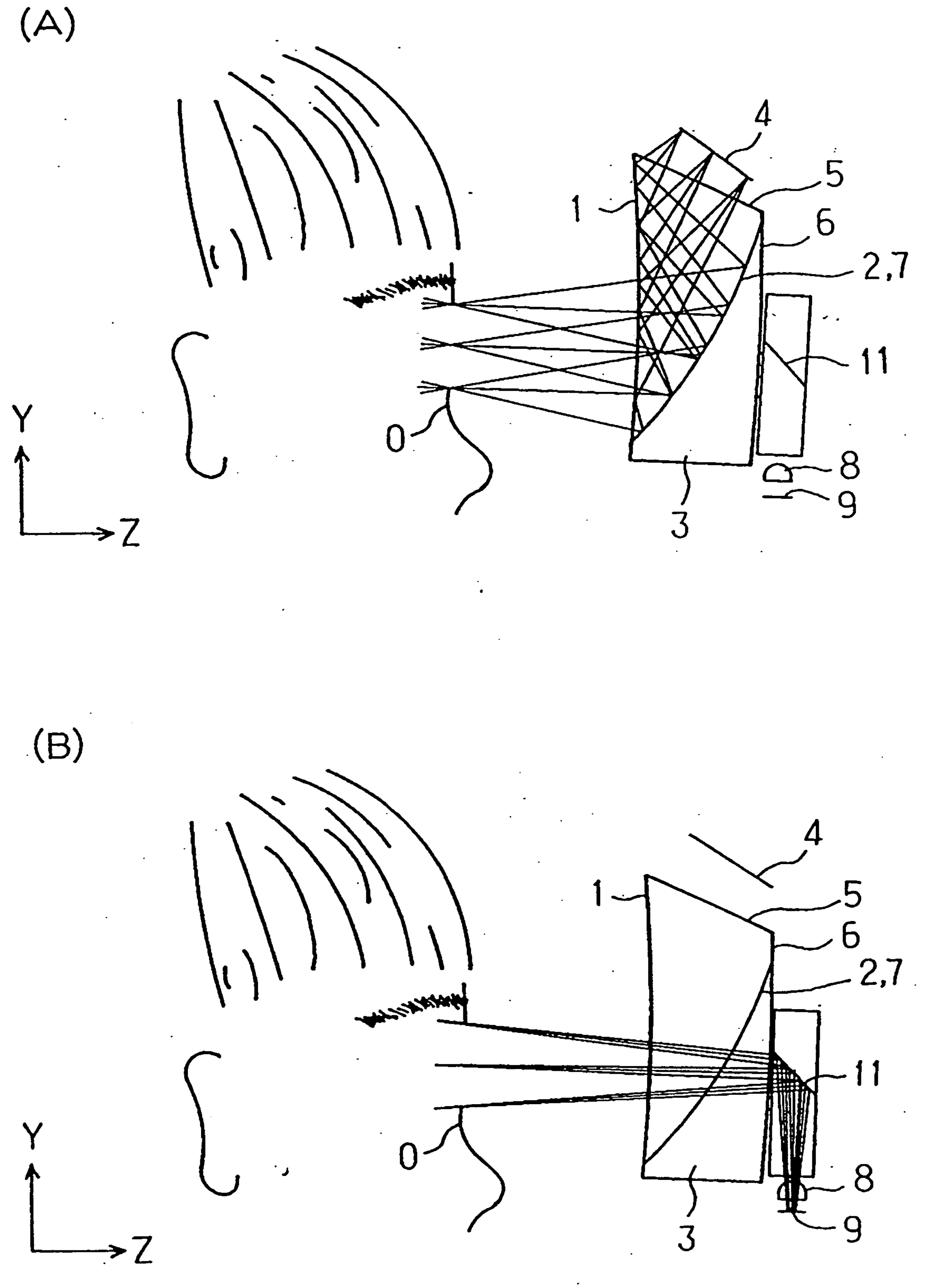
【図９】 Fig. 9



【図１０】 Fig. 10

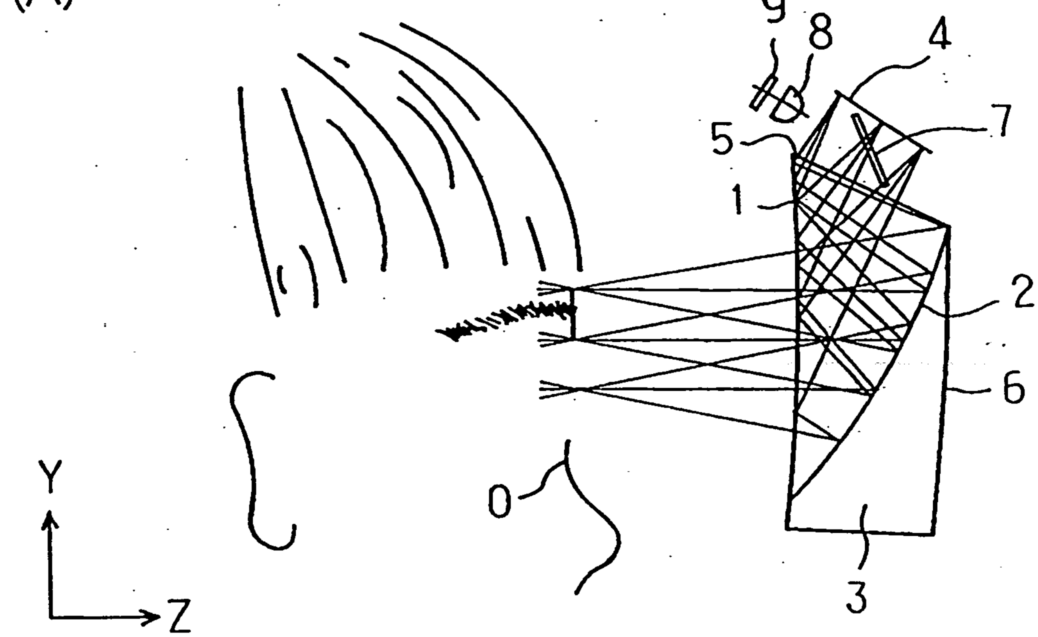


【図１１】 Fig 11

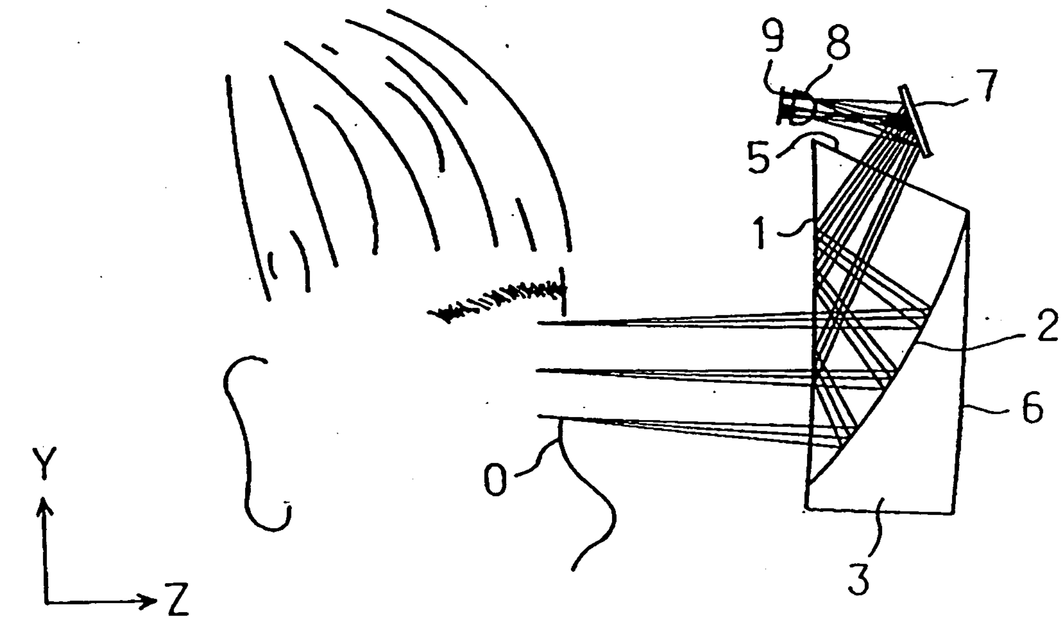


【図１２】 Fig. 12

(A)



(B)



[Name of the Document] Abstract

[Abstract]

[Object] An object of the present invention is to attain a display device having a visual line detecting system of a head-mount display type for controlling the video information which is displayed on display means on the basis of visual line information of the observer.

[Constitution] In the display device, there are provided an observation system which guides a light of video information in a visible wavelength region displayed by display means to the eye of the observer without forming an image thereof on the way by using an optical system having a reflecting face, so as to observe a virtual image of the video information; and a visual line detecting system which causes a non-visible light from light source means to enter the eye of the observer, and guides the light beam reflected from the eye onto a surface of an image pick-up means through a part of the optical system by use of an imaging optical system provided independently of the optical system, so as to detect a visual line of the eye of the observer by use of a signal from the image pick-up means, whereby the video information displayed by the display means is controlled by use of visual line information

from the visual line detecting system.

[Elected Drawing] Fig. 1